CEMENT AND LIME MANUFACTURE

PUBLISHED 20TH OF EACH MONTH. PRICE 1/- A COPY. ANNUAL SUBSCRIPTION 12/- POST FREE.

PUBLISHED BY
CONCRETE PUBLICATIONS LIMITED
14 DARTMOUTH STREET, LONDON S.W.1

TELEPHONE: WHITEHALL 4581
TELEGRAPHIC ADDRESS:
CONCRETIUS, PARL. LONDON

PUBLISHERS OF
"CONCRETE & CONSTRUCTIONAL ENGINEERING"
"CONCRETE BUILDING & CONCRETE PRODUCTS"
"CEMENT & LIME MANUFACTURE"
"THE CONCRETE YEAR BOOK"
"CONCRETE SERIES" BOOKS, ETC.

VOLUME X. NUMBER 10 OCTOBER 1937

The Cooling of Rotary Clinker.—II.*

By W. GILBERT, Wh.Sc., M.Inst.C.E.

(16) As a preliminary to the cooling experiments, heating curves were obtained for the 47.6-gram, 23.0-gram, and 11.0-gram lumps listed in Table III. With a furnace temperature of 2,000 deg. F. clinker lumps of each grade were inserted for periods of 1, 2, 3 minutes, etc., and the mean lump temperature at the end of each period was ascertained by the water calorimeter. The heating curves so obtained were analysed in order to obtain the conductivity of the material.

Heating Curve for Clinker Lumps of the 47.6-gram Grade.

(17) The heating results for the 47.6-gram grade are shown in Table V.

TABLE V.—HEATING CURVE FOR 47.6-GRAM GRADE.
(Average lump diameter 1.31 inches.)

Time in furnace (minutes).	Furnace temperature (deg. F.).	Lump weight in grammes.	Temperature of water in calorimeter.		Lump temperature by calorimeter (deg. F.)
			Initial (deg. F.)	Final (deg. F.)	
(1)	(2)	(3)	(4)	(5)	(6)
1	2,000	44.74	62.8	81.8	1,011
2	2,000	43.79	63.4	90.2	1,431
3	2,000	48.67	61.4	95.1	1,609
4	2,000	46.99	51.1	86.0	1,710
5	2,000	49.64	62.1	100.2	1,778
6	2,000	49.81	61.4	101.1	1,843
8	2,000	47.87	61.7	100.9	1,892
11	2,000	49.37	63.9	105.1	1,929
110	2,000	40.86	62.7	96.9	1,925

The average relates to Col. (3). AVERAGE, 47.61

* Part I was given in our issue for July last.

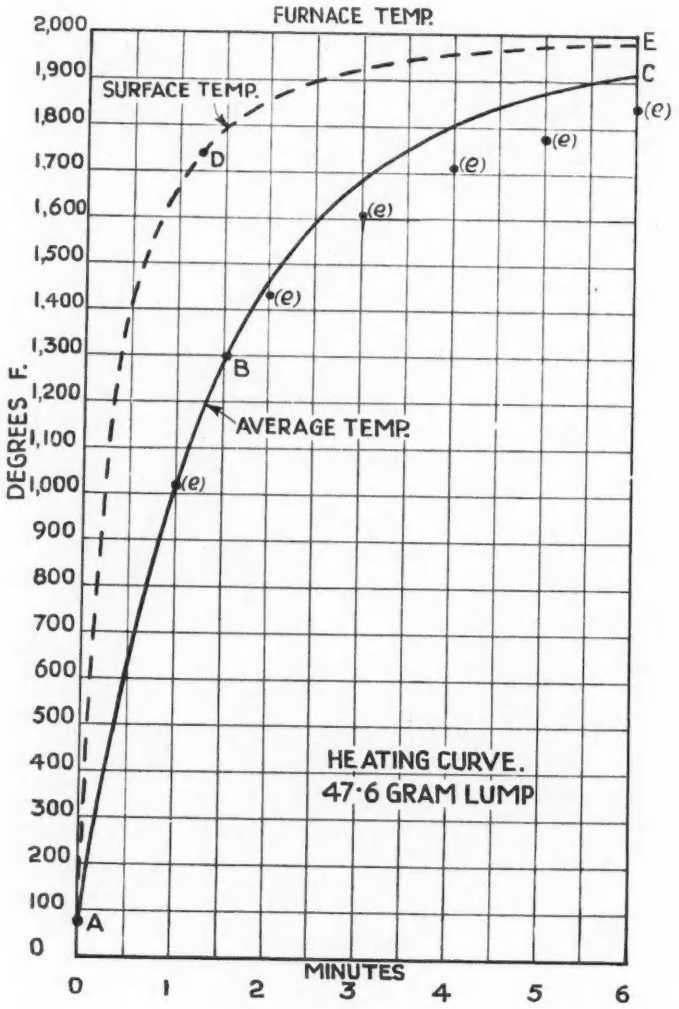

FURNACE TEMP.
SURFACE TEMP.
AVERAGE TEMP.
HEATING CURVE.
47·6 GRAM LUMP
DEGREES F.
MINUTES
2,000
1,900
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
A
B
C
D
E
(e)

Fig. 8.

The actual lump weight used in each instance is shown in col. (3). The temperatures in col. (6) are calculated to a water equivalent of 525 grammes, and to a clinker specific heat of 0.24.

(18) The last line in col. (6) shows that after a 40.86-gram lump had been in the furnace for 110 minutes its average temperature, as determined by the water calorimeter, was only 1,925 deg. F., or 75 deg. less than the furnace temperature. The difference is mainly due to radiation loss during transit. After allowing for this, and for the variation in the weight of individual lumps, an average temperature curve was obtained; the essential period from 0 to 6 minutes is shown at ABC on *Fig.* 8. At six minutes the lump average temperature was 1,917 deg. F. and the corresponding value of *Trp* (the temperature rise per cent.) was 95.7. The experimental points are shown at (*c*). On the original graph the average temperature curve is drawn for a period of twelve minutes, and it is then seen that the line ABC on *Fig.* 8 cannot be far from the truth.

Analysis of Heating Curve.

(19) The curve ABC is now analysed in order to obtain the surface temperature curve ADE, the mean value of H_t, and finally the conductivity of the clinker. [For list of symbols, see para. (50).] The lumps were heated in a closed firebrick chamber, the interior surfaces of which were at a uniform temperature of 2,000 deg. F. Heat is supplied mainly by radiation.

The formula for maximum radiation (termed black body radiation) has been well established by experiment. It is as follows:

$$Q = \frac{1.73 \times T^4}{60 \times 10^9} \quad .. \quad .. \quad .. \quad .. \quad (1)$$

where Q = heat radiated in B.T.U. per square foot per minute,
T = absolute temperature of the radiating surface in degrees F., or temperature F. + 461.

(A table giving the black body radiation for each deg. F. between 0 and 2,590, together with a description of the emission and absorption factors, E_1, E_2, was given in *Cement and Cement Manufacture*, March, 1933, p. 79.)

In this instance the area of the radiating surface of the firebrick chamber is about eighteen times the area of the receiving surface of the clinker lump, and the product of the emission and absorption factors E_1 E_2 is taken at 0.9. The heat supplied by convection is relatively small, since the air in the furnace is practically at rest. The value of H_c is taken at 2.0.

(20) The figures obtained by analysing the heating curve are given in Table VI. The heating time of six minutes is divided into eight periods as shown in col. (1). The temperature at the beginning, and at the end of each period, as taken from curve ABC on *Fig.* 8, is shown in cols. (2) and (3), and the lump temperature rise in each period is shown in col. (4).

Col. (7).—If the lump temperature rises "*a*" degrees the heat supply is $a\phi$ B.T.U. per lb., or $\frac{a\phi}{S}$ B.T.U. per square foot. The lump surface S in square

feet per pound (see Table III) is 0.3568, and the figures in col. (7) are obtained from those in col. (4) on multiplying by $\frac{\phi}{S}$, or 0.673.

TABLE VI.—ANALYSIS OF HEATING CURVE FOR 47.6-GRAM LUMP.
D = 1.31. S = 0.3568.

Period (Minutes).	Average lump temperature.		Temperature rise in period (deg. F.)	Heat received in period. B.T.U. per sq. ft.			Mean lump surface temperature (deg. F.)	Heat transmitted per sq. ft. per hour per deg. F. (H_t).
	Initial (deg. F.)	Final (deg. F.)		By radiation.	By convection.	Total.		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0 to ½	60	630	570	370	13	383	1,229	59.5
½ to 1	630	1,025	395	258	7	265	1,564	73.0
1 to 1½	1,025	1,285	260	171	4	175	1,742	81.4
1½ to 2	1,285	1,463	178	117	3	120	1,832	86.0
2 to 3	1,463	1,684	221	146	3	149	1,900	89.4
3 to 4	1,684	1,805	121	79	2	81	1,947	92.0
4 to 5	1,805	1,873	68	45	1	46	1,970	92.0
5 to 6	1,873	1,917	44	29	1	30	1,981	94.7
			1,857	1,215	34	1,249	1,830	73.4

(21) DETERMINATION OF LUMP SURFACE TEMPERATURE.—The figures in cols. (5), (6) and (8) have to be found by trial. Take, for instance, the period from 1 to 1½ minutes, and assume the mean lump surface temperature to be 1,742 deg. F. (see point D on *Fig.* 8). From col. (7), the heat transmitted to the lump in the half-minute period is 175 B.T.U. per square foot.

(*a*) *Heat transfer by radiation.*—From formula (1), the black body radiation at 2,000 deg. F. is 1,058, and at 1,742 deg. F. it is 679, the difference being 379 and, since $E_1 E_2 = 0.90$, we have

	B.T.U. per square foot.
Heat radiated to lump in half-minute period—	
$379 \times 0.9 \times \frac{1}{2}$	170.6

(*b*) *Heat by transfer by convection.*—The temperature difference between the hot air and the lump surface is (2,000 − 1,742), or 258 deg. F., and $H_c = 2.0$, hence the heat transfer is

$\frac{2.0 \times 258 \times \frac{1}{2}}{60}$	4.3
Total	174.9

(22) The values for radiation are given per square foot per minute, but H_c is expressed per square foot per hour, as is usual. Since the area of the interior surface of the muffle is large compared with the lump surface, the air temperature is, with small error, taken at 2,000 deg. F.

The value assumed in para. (21) for the average surface temperature during the period 1 to 1½ minutes is seen to be satisfactory. Proceeding on these lines

all the figures shown in cols. (5), (6) and (8) can be obtained, and the surface temperature curve ADE drawn on *Fig.* 8. The rapid rise of the surface temperature during the early stages of heating is a characteristic feature.

(23) VALUE OF H_t.—The average surface temperature for the period 0 to 6 minutes can be measured from the graph, or it may be obtained from Table VI by multiplying the average surface temperature in each period by the time and dividing the sum by 6. The result in either case is 1,830 deg. F., hence the mean temperature difference between the interior surfaces of the furnace and the clinker for the period of 0 to 6 minutes is 2,000 — 1,830, or 170 deg. F.

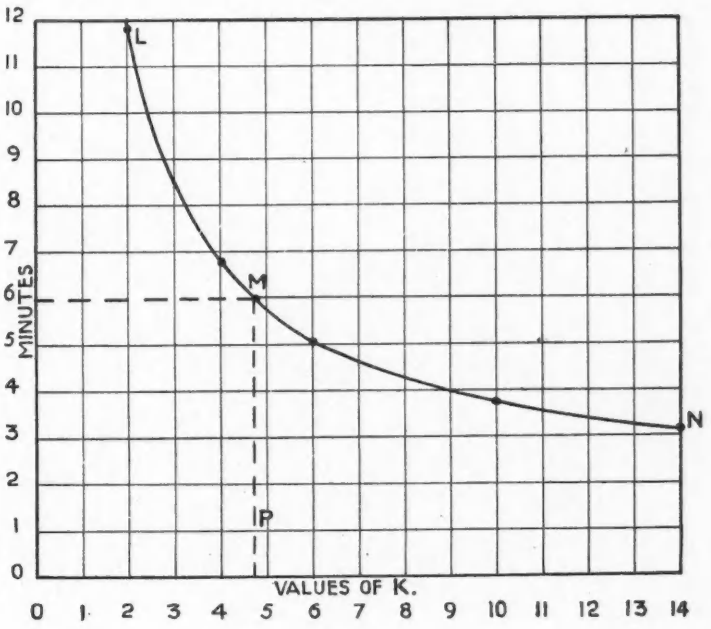


Fig. 9.

The mean value of H_t is found as follows. The total heat received per square foot of lump surface in six minutes is, from col. (7), 1,249 B.T.U., hence

$$\frac{H_t \times 170 \times 6}{60} = 1{,}249, \text{ and } H_t = 73.4$$

The value of H_t for each short period is shown in col. (9).

(24) DETERMINATION OF CONDUCTIVITY.—Having found the surface temperature curve on *Fig.* 8, and the mean value of H_t, it remains to determine the conductivity (K). The surface temperature and the average temperature of a spherical body which has been surrounded by a source of heat at a uniform temperature for a definite period can be calculated with the aid of a suitable

Fourier Series. Examples will be found in textbooks on the mathematical theory of heat conduction. The initial particulars required are H_t, K, g, ϕ, and D. The result, for any value of M, is obtained as the sum of a number of terms, which rapidly diminish. Curves similar to ABC and ADE on *Fig.* 8 may then be drawn.

The calculations are based on the following simple assumptions. (*a*) That the rate at which heat can be conducted through a flat plate, per square foot of area, is directly proportional to the temperature difference between the two sides of the plate, and inversely proportional to the thickness. (*b*) That the surrounding hot surface remains at a uniform temperature throughout the experiment. (*c*) That the rate of heat supply to the sphere is always strictly proportional to the temperature difference. The last assumption, although necessary for mathematical simplicity, is not true when heat is supplied by radiation, as will be seen from col. (9) of Table VI, but a suitable allowance can usually be made.

(25) Using a Fourier Series calculations are now made which relate to the experimental heating of a 47.6-gram lump from 60 deg. to 1,917 deg. F. in six minutes as shown in *Fig.* 8, the furnace temperature being 2,000 deg. F. The quantities given include H_t, the average unit rate of heat transmission 73.4, see para. (23), the lump diameter 1.31 in., the specific heat 0.24, the density 154, and the time six minutes. K has to be determined.

(26) A value is assumed for K, and the time M which is required in order that the lump average temperature may rise from 60 to 1,917 deg. F. is calculated. The process being repeated, a number of corresponding values is found for K and M which are shown by the curve LMN on *Fig.* 9. Since the time actually required was six minutes, the curve shows that the value of K must have been 4.72 (see ordinate PM). It is interesting to note that the time required approaches a steady value of 1.73 minutes as K becomes very large.

(27) The heating curves for the 23-gram lump and for the 11-gram lump were also analysed, and the conductivity determined in each case. The value of K was found to be 5.0 for the 23-gram lump and 4.82 for the 11-gram lump. A further investigation showed that the conductivity was approximately 6.0 at the commencement of each heating curve, falling to about 4.0 as the average lump temperature approached 2,000 deg. F. Finally a value of $K = 5.0$ was adopted for general use.

Approximate Formula for the Cooling of a Sphere.

(28) The statements made in para. (24) with reference to the heating of a spherical body apply equally to cooling. Calculations made by the aid of a Fourier Series are, however, very tedious, and it is sufficient for the present purpose if the time required to cool a spherical lump through 95 per cent. of the full temperature range can be calculated with reasonable speed and accuracy when H_t, D, g, ϕ, and K are given.

For this purpose an approximate method has been devised. Referring to *Fig.* 10, suppose the sphere of clinker to be replaced by a sphere A, which is

covered by a number of curved slabs B, of thickness x. The sphere A is assumed to have the same surface area, weight, and specific heat as the sphere of clinker, but its conductivity is infinite, hence its temperature during heating or cooling will be uniform throughout.

The slabs B have the same surface area and conductivity as the clinker sphere, but their specific heat is zero. The crevices C are filled with non-conducting material. Under these conditions the time required to lower the average temperature of the sphere A through 95 per cent. of the full temperature range

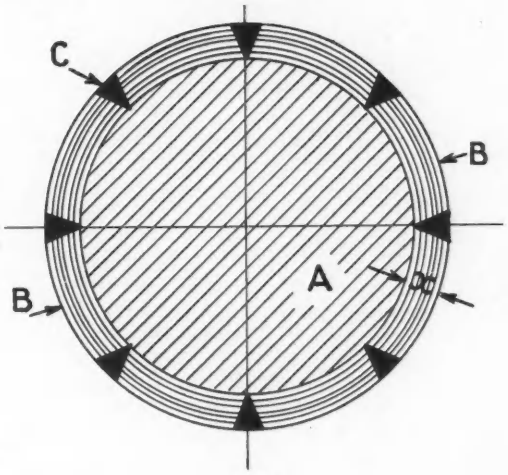


Fig. 10.

available can be calculated without much difficulty, and the result will apply to the cooling of the clinker sphere if the thickness x is rightly chosen.

(29) The following formulæ connect H_t, K, S, M, ϕ and x with Tfp, the temperature fall per cent. Since the rate of heat supply is assumed to be proportional to the temperature difference, the actual temperatures do not affect the time required.

$$M = \frac{2.302}{Z} \log \left(\frac{100}{100 - Tfp}\right) \quad .. \quad .. \quad .. \quad (2)$$

$$Z = \frac{SH_tK}{60\ \phi\ (K + H_tx)} \quad .. \quad .. \quad .. \quad .. \quad (3)$$

$$H_t = \frac{60Z\phi K}{KS - 60\ Z\phi x} \quad .. \quad .. \quad .. \quad .. \quad (4)$$

Formulæ (2) and (3) are used to calculate the time of cooling when the other quantities are given. Formula (4) will give H_t if the time M is known, since Z can then be obtained from formula (2). The meaning of the symbols is given in para. (50). The formulæ are equally applicable to heating, if Tfp is replaced by Trp.

(30) Formulæ (2), (3), and (4) relate especially to heating or cooling through 93 to 97 per cent. of the full temperature range. It is not possible to select a value for x which will make the formulæ true for all values of Trp or Tfp, but within the limits stated x will lie between 0.105 D and 0.125 D for all values of H_t, K, D, g, and ϕ that are likely to occur in clinker cooling. Values of $\frac{x}{D}$ which are suitable for calculations in connection with each cooling curve are given in Table VIII.

(31) The formulæ can be usefully employed in the design of clinker coolers of various types. They are also applicable to the heating or cooling of cubes or rectangular blocks; for cubes a suitable value for x is one-sixth of the side, and for a 9 in. by $4\frac{1}{2}$ in. by 3 in. brick x equals five-eighths of an inch.

Analysis of a Typical Cooling Curve.

(32) The cooling curve selected for analysis is BAC in *Fig.* 6; it relates to grade III clinker, the nominal value of W being 5,890. The clinker is cooled from 1,950 deg. F. to 154 deg. F. in 2.72 minutes and, since the available temperature range is (1,950 − 60), the value of Tfp is $\frac{1,796 \times 100}{1,890} = 95.0$.

At the commencement of cooling the total rate of heat transfer from clinker to air (H_t) is about 37 B.T.U. per square foot per hour per deg. F. temperature difference, but near the end of the cooling curve the value of H_t has fallen to 23. There are two reasons for this: (*a*) Cooling by radiation occurs mainly over the earlier part of the curve, and (*b*) the unit rate of heat transfer by convection (H_c) falls off somewhat as cooling proceeds.

The object of analysing the cooling curve is to separate out the proportion of the cooling which is done by radiation and to obtain an average value for H_c. Under the conditions which occur in practice only a small proportion of the cooling will be done by radiation, and the law of cooling by radiation is known already.

(33) Referring again to *Fig.* 6, a portion of the cooling curve BAC which shows average temperatures is reproduced to a larger scale in *Fig.* 11; it is marked OPQ, and it is desired to obtain from it, by way of example, the corresponding portion of the surface temperature curve marked UVW.

The first step is to draw a cooling curve which will have the same time and temperature range as BAC, that is will pass through points B and C on *Fig.* 6, but the value of H_t is to be uniform throughout. Under these conditions a Fourier Series can be employed, and much time will be saved if an approximate value of H_t is first obtained from formulæ (2) and (4).

Since $M = 2.72$, and $Tfp = 95.0$, formula (2) is first used to obtain Z.

$$Z = \frac{2.302}{2.72} \log \left(\frac{100}{100 - 95} \right).$$

Hence $Z = \frac{2.302 \times 1.3010}{2.72} = 1.101$.

(34) We also have $K = 5.0$, $\phi = 0.24$, $D = 0.61$, and $S = 0.767$. The value for x in this instance is $0.108\,D$, hence $x = 0.61 \times 0.108 = 0.0659$. Inserting the above values into formula (4) we obtain

$$H_t = \frac{60 \times 1.101 \times 0.24 \times 5.0}{5 \times 0.767 - (60 \times 1.101 \times 0.24 \times 0.0659)}$$

$$\therefore \quad H_t = \frac{79.30}{3.835 - 1.045} = 28.44$$

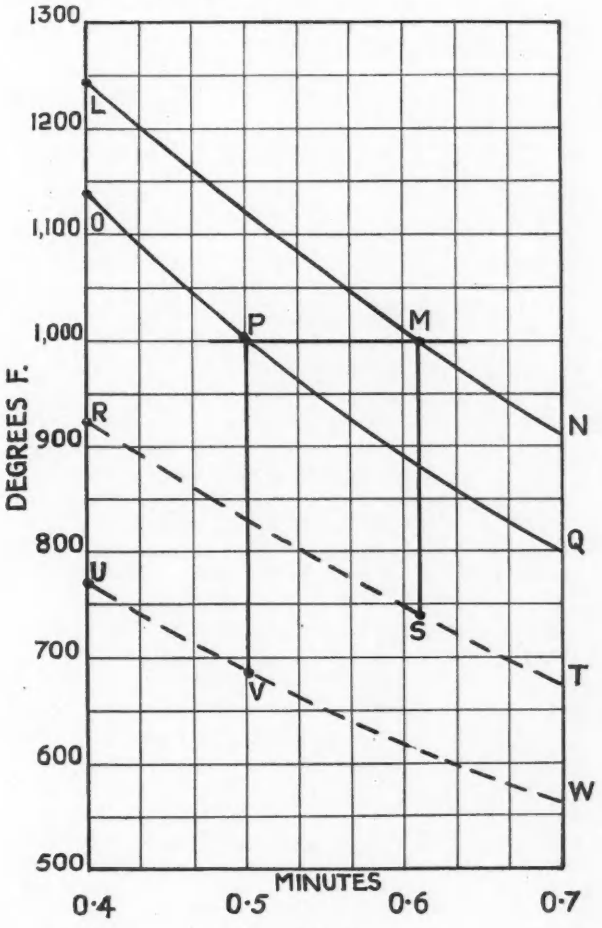


Fig. 11.

Having given $H_t = 28.44$, which was subsequently found to be correct, a Fourier Series is used to obtain an average temperature curve, part of which is

shown at LMN, and a surface temperature curve part of which is shown at RST on *Fig.* 11. It is seen that the actual curve OPQ falls more quickly than the Fourier curve LMN in the earlier stages.

(35) Points on the actual surface temperature curve UVW are obtained as follows. Draw a horizontal line PM at any suitable temperature cutting the experimental curve OPQ at P and the Fourier curve LMN at M. At the points P and M the value of $Tf\phi$ is the same on each curve, and the ordinates MS and PV will be very nearly proportional to the rate at which each lump is losing heat.

It is found by drawing a tangent to the Fourier curve at point M that the lump temperature is falling at the rate of 1,028 deg. per minute, and by drawing a tangent to the actual curve at point P the lump temperature is seen to fall at the rate of 1,240 deg. per minute, also MS is 265 deg. F. Hence

$$PV = \frac{1{,}240}{1{,}028} \times 265 = 320 \text{ deg. F.}$$

A number of points can thus be obtained and the actual surface temperature curve completed. It is shown at BDK on *Fig.* 6.

(36) The approximate accuracy of the method described in para. (35) may be demonstrated by drawing two cooling curves Aa and Ba, together with the corresponding surface temperature curves As and Bs with the aid of a Fourier Series. The values for D, K, g, and ϕ are to be the same as in para. (34), but for

TABLE VII.—GRADE III CLINKER. W = 5,890. ANALYSIS OF COOLING CURVE ON FIG. 6.

Period (Minutes).	Average temperature fall in period (deg. F.)	Heat given up in period (B.T.U. per sq. ft.)	Mean surface temperature in period (deg. F.)	Heat radiated in period (B.T.U. per sq. ft.)
(1)	(2)	(3)	(4)	(5)
0 to 0.1	257	80.5	1,499	34.3
0.1 to 0.2	213	66.6	1,153	15.7
0.2 to 0.4	340	106.5	890	15.2
0.4 to 0.6	248	77.5	685	7.6
0.6 to 1.0	312	97.5	519	8.0
1.0 to 1.5	212	66.4	350	4.3
1.5 to 2.0	122	38.2	239	2.0
2.0 to 2.72	92	28.8	160	1.4
	1,796	562.0		88.5

the curve Aa the value of H_t is to be 28.44 as before, and for the curve Ba it is to be about 30 per cent. greater, say, 37.0. It will be found on trial that the surface temperature curve Bs can be obtained from the surface curve As by the method described in para. (25), the average error in the ordinate length PV on *Fig.* 11 being about ½ per cent. The method is based on *Fig.* 10.

(37) COOLING BY RADIATION.—The proportion of the cooling which is done by radiation can now be separated out. During cooling each lump radiates to surroundings which are assumed to be at a temperature of 60 deg. F. The calculation details are given in Table VII.

(38) Col. (1) shows the short periods into which the total cooling time of 2.72 minutes is divided. Col. (2) shows the fall of the lump average temperature in each period; these figures are obtained from the curve BAC. Col. (3) is obtained from col. (2) on multiplying by $\frac{\phi}{S}$, where $\phi = 0.24$ and $S = 0.767$. Col. (4).—The figures are taken from the curve BDK on *Fig.* 6, which was obtained by the method described in para. (35).

Col. (5).—Taking, for instance, the first period, the mean surface temperature is 1,499 deg. F. The black body radiation from 1,499 deg. F. to 60 deg. F. is (425.5 − 2.1) or 423.4 B.T.U. per square foot per minute. The emission and absorption factors E_1 and E_2 are each taken at 0.9, and the length of the period is 0.1 minute, hence the heat radiated is

$$423.4 \times 0.9 \times 0.9 \times 0.10 = 34.3 \text{ B.T.U. per square foot.}$$

(39) DETERMINATION OF H_c.—The total heat radiated is 88.5 B.T.U. per square foot as shown in col. (5). Hence from col. (3) the heat removed by convection will be

$$562.0 - 88.5, \text{ or } 473.5 \text{ B.T.U. per square foot.}$$

The average surface temperature, as measured from the curve BDK for the period 0 to 2.72 minutes, is 440 deg. F., and the mean air temperature [see para. (13)] is 63 deg. F.; hence the mean temperature difference (air and clinker) is (440 − 63) or 377 deg. F. and

$$\frac{H_c \times 377 \times 2.72}{60} = 473.5$$

$$\therefore \quad H_c = \frac{473.5 \times 60}{377 \times 2.72} = 27.7$$

Air Velocity Between Clinker Lumps on Grid.

(40) Referring to Table II, the values of V and W given in cols. (3) and (4) relate to the movement of the air in the outlet C of the air measuring box (see *Fig.* 1). When the air flows between the clinker lumps which rest on the grid its velocity is increased. The maximum air velocity occurs at section AA (*Fig.* 12) which contains a great circle of each lump, but the average velocity with which the air moves over each lump is somewhat less. In the calculations which follow the mean air velocity is reckoned on an area equal to that of the cooling grid, when reduced by two-thirds of the great circle area of each clinker lump which rests upon it. The symbols V and W which relate to the full area of the cooling grid are then replaced by V_a and W_a.

(41) For instance, when cooling grade V clinker there would be (from Table III) twenty lumps, averaging 0.337 in. in diameter, resting on the grid which is 3 in. square. The lump great circle area is 0.0892 sq. in., and the airway used for calculation purposes is 9.0 − (20 × $\frac{2}{3}$ × 0.0892) or 7.811 sq. in. Hence for grade V clinker

$$W_a = \frac{W \times 9.0}{7.811} = 1.152\, W.$$

The values of V_a and W_a listed in cols. (3) and (4) of Table VIII are obtained in this manner from the values of V and W listed in cols. (3) and (4) of Table IV.

Values of H_c for all Cooling Curves.

(42) Values of H_c (the rate of heat transmission by convection per square foot per hour per deg. F.) have been obtained for all the cooling curves listed in Table IV in accordance with the method illustrated by Table VII, and the result is shown in Table VIII. In each grade and for each cooling curve the

TABLE VIII.—RELATION BETWEEN V_a, W_a, H_c AND D, FOR ALL COOLING CURVES.
(Cooling period 95 per cent. in all cases, see Table IV.)

Grade.	Lump diameter (inches)	V_a (ft. per minute at 60 deg.F.)	W_a (lb. per sq. ft. per hour).	Heat removed in cooling period per sq. ft. of lump surface (B.T.U.).		Mean surface temperature for cooling period (deg. F.)	Mean value of H_c for cooling period.		Value of $\frac{x}{D}$ for cooling period.
				By convection.	By radiation.		By experiment.	By formula (5).	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
44 gr.	1.28	1,422	6,507	1,030	134	371	25.8	24.3	0.1153
,,	1.28	593	2,717	1,165	223	397	16.0	15.7	0.1111
,,	1.27	169	773	785	335	455	9.4	8.4	0.1095
23 gr.	1.05	1,373	6,279	842	127	373	28.4	25.7	0.1115
,,	1.02	573	2,622	730	212	416	15.2	16.6	0.1073
,,	1.03	163	747	679	271	427	10.5	8.9	0.1053
III	0.61	1,450	6,640	474	89	440	27.7	32.1	0.1080
,,	0.60	605	2,772	423	130	476	17.2	20.7	0.1063
,,	0.57	172	789	363	163	456	11.7	11.1	0.1050
V	0.34	1,482	6,785	138	9	295	35.4	39.5	0.1059
,,	0.34	618	2,834	134	15	300	22.4	25.5	0.1065
,,	0.33	176	806	115	22	354	14.3	13.6	0.1060
VI	0.20	1,715	7,845	83	4	280	54.1	50.5	0.1060
,,	0.21	715	3,276	85	7	294	33.5	32.6	0.1060
,,	0.21	204	932	79	12	303	18.6	17.4	0.1060
VII	0.15	1,745	7,979	62	3	292	58.5	56.9	0.1060
,,	0.15	728	3,332	60	5	300	33.0	36.8	0.1060
,,	0.15	207	948	58	7	314	17.5	19.6	0.1060

lump diameter varies a little, and the corresponding values of S also vary. The correct diameters are shown in col. (2), and the value of S in each case is $0.4674 \div D$. Cols. (5) and (6) give the heat removed in B.T.U. per square foot during each cooling period of 95 per cent. by convection, and by radiation. Col. (7) shows the mean surface temperature as obtained from the surface temperature curve in each case. Values of H_c as obtained by experiment are shown in col. (8). Col. (10) shows the effect of variations in H_c and D on the value of $\frac{x}{D}$ for each cooling curve when $Tfp = 95.0$.

Formula and Graph Connecting H_c, W_a and D.

(43) It is possible to express H_c in terms of W_a and D for all the cooling curves with reasonable accuracy by a single formula. In each of the grades shown on Table VIII the three values of log W_a were plotted against the three values of log H_c, and for each grade a straight line was approximately obtained. The lines representing each grade had nearly the same slope, and it was deduced that H_c varied as $W_a^{0.50}$.

(44) Values for N were next obtained from each line of Table VIII on the assumption that $H_c = \frac{W_a^{0.50}}{N}$. Values of log N were plotted against corresponding values of log D, and again the points came approximately on to a straight line. A suitable index for D was thus found to be 0.35, and the formula became

$$H_c = \frac{0.328 W_a^{0.5}}{D^{0.35}} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (5)$$

H_c, W_a, and D are defined in the list of symbols in para. (50). By comparing cols. (8) and (9) in Table VIII it will be seen to what extent the formula actually represents the experimental results.

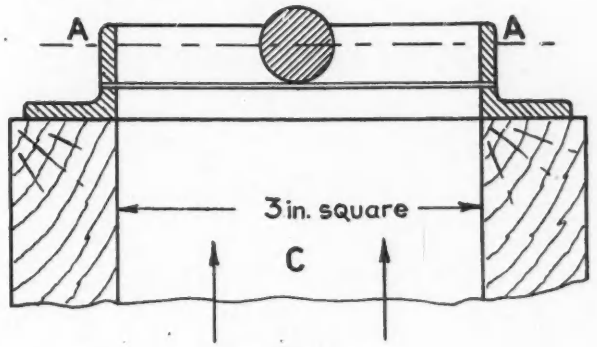


Fig. 12.

(45) From formula (5) a graph which shows the relation between H_c and W_a for each grade has been prepared (see *Fig.* 13). The lump diameters in each grade are given in Table VIII, and are drawn full size in *Fig.* 5.

Effect of Surface Roughness on Values of H_c.

(46) In order to find whether the rather rough surface of a lump of rotary clinker facilitated cooling by convection, some experiments were made on a smooth copper ball with a diameter of 0.77 in. It was heated in the muffle furnace to 1,000 deg. F. and then cooled on the grid, the value of W being 2,460 and of W_a 2,548. A reliable heating curve could not at first be obtained since the bright surface of the copper sphere did not readily absorb heat from the furnace. After a few heatings, however, the surface became a dull slate colour and consistent results were then obtained.

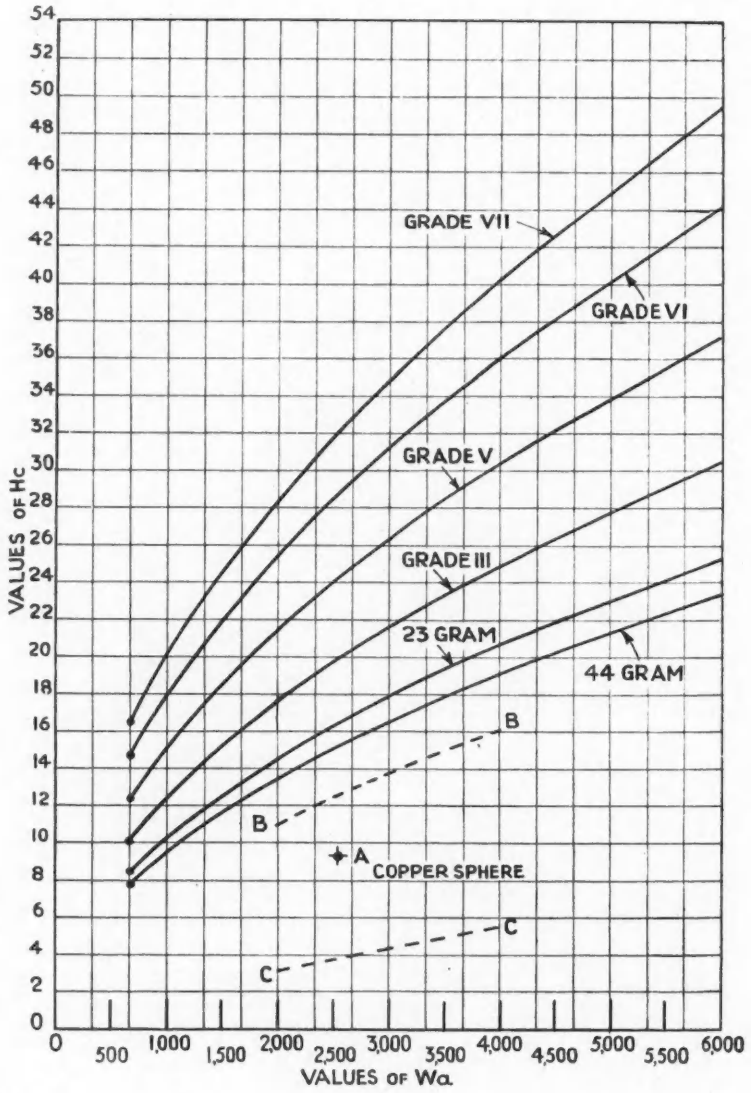

VALUES OF Hc
VALUES OF Wa
GRADE VII
GRADE VI
GRADE V
GRADE III
23 GRAM
44 GRAM
B
B
A
COPPER SPHERE
C
C
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
5,500
6,000

Fig. 13.

(47) On the grid the temperature of the sphere fell from 950 to 125 deg. F. in eight minutes. In this case $K = 2{,}300$, $\phi = 0.098$, and $S = 0.1687$. Owing to the high value of K the sphere surface temperature was within 1 deg. F. of the average temperature throughout the cooling curve.

The mean surface temperature was 357 deg. F. During the eight-minute period the heat per square foot removed by radiation, ($E_1 E_2 = 0.81$) was 111 B.T.U., and by convection 368 B.T.U. The average value of H_c was 9.3. This result is shown in the correct position by point A in *Fig.* 13; it indicates that the rough surfaces of rotary clinker facilitate considerably the removal of heat by convection.

(48) The effect of a smooth surface is further illustrated by the lines BB and CC on *Fig.* 13. The line BB gives values of H_c for air flowing at right angles to a smooth iron rod, and the line CC gives values of H_c for air flowing inside a smooth iron pipe. The diameter in each case is 0.60 in., which is the same as that of grade III clinker. These results are obtained from formulæ due to Dr. Schack. The improvement in the rate of heat transfer when the air flows at right angles to the iron surface is noticeable.

Effect of Conductivity on Determination of H_c.

(49) Most of the published results of experiments on convection relate to the transfer of heat from air or furnace gases to or from steel tubes or rods. The conductivity of iron is about 84 times that of rotary clinker, hence in the experiments cited it is probable that the average temperature of the metal, and the surface temperature, only differed by 2 or 3 degrees. It is then much easier to obtain the value of H_c.

Symbols.

(50) A uniform system of units, such as the pound, foot, and hour has not been adhered to. Conductivity, for instance, in accordance with engineering practice, has been expressed per square foot per hour per inch thickness. The clinker lump diameter D is given in inches, and the time M in minutes, but H_t and H_c are expressed per square foot per hour, as is usual.

W_a = weight of air in lb. per hour per square foot of the reduced area between the clinker lumps on the cooling grid [see para. (40)].

V_a = air velocity in feet per minute at 60 deg. F. through the reduced area between the clinker lumps on the cooling grid.

K = conductivity for heat expressed in B.T.U. per square foot per hour per deg. F. per inch thickness.

H_t = total rate of heat transfer (convection + radiation) expressed in B.T.U. per square foot per hour per deg. F. temperature difference.

H_c = rate of heat transfer by convection, expressed as above.

D = diameter of clinker lump in inches.

S = surface of clinker lump in square feet per pound (see Table III).

g = weight of clinker lump in lb. per cubic foot, taken at 154.

ϕ = specific heat of clinker, taken at 0.24.

M = time in minutes.

x = thickness of screen-plates in inches (see *Fig.* 10).

Trp = temperature rise per cent.

Tfp = temperature fall per cent.

E_1 and E_2 = emission and absorption constants for use with formula (1), see para. (19).

Design and Operation of Modern Lime Works.—VIII.*

By N. V. S. KNIBBS, D.Sc.

GAS-FIRED KILNS (CONTINUED).

Gas Application.

The simplest way to apply gas to a shaft kiln is through side burners—ports in the walls connected to the gas flue—and the early kilns all had side ports. At first the gas ports were usually large openings, serving also as combustion chambers, but such gas application is no longer of interest. Gas ports at the side have the advantage of simplicity and accessibility, but in other respects they are the least

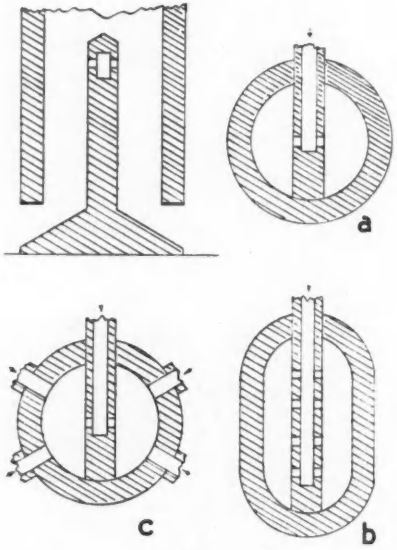


Fig. 28.

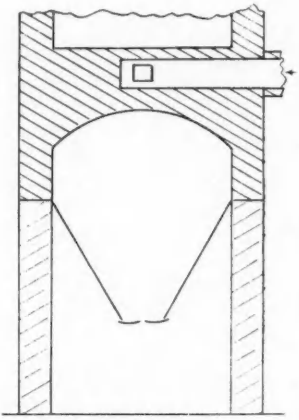


Fig. 29.

suitable of the possible methods of application. If the kiln is charged with stone of the same size over its whole cross-section the easiest passage for the gas is up the walls, whilst if small stone is charged around the periphery[1] its presence at the gas inlets increases the resistance to gas entrance. However, with large stone of uniform size a gas kiln may successfully be operated with side burners and the approximate limit of size has already been mentioned[2]. For higher

* Previous articles in this series appeared in our issues for January, February, March, April, May, August and September this year.

[1] For example, by the charging device described in "Cement and Lime Manufacture," March, 1937, p. 78.

[2] *ibid.* September, 1937, p. 247.

capacities or for smaller or less uniform stone, if side burners are to be used, it is necessary to alter the cross-section of the kiln at the burning zone and to depart from the cylindrical shape. Gas kilns of oval or rectangular shape (with rounded corners) at the gas-inlet zone or throughout their full height are widely used in Europe outside Great Britain. Examples are shown in *Figs.* 34 to 37.

Central Gas Ports.—To introduce the gas at or near the centre of a cylindrical kiln, or on the major axis of a kiln of oblong cross-section, a gas-flue may be built in refractory blocks on a fire-brick wall carried across the kiln as in *Fig.* 28. In a cylindrical kiln this duct generally has two or four ports near the kiln centre, whilst if the kiln is of oblong section there may be several ports on each side, as in *Fig.* 28b. These internal gas openings may also be combined with outside ports, as in *Fig.* 28c.

Such a kiln must necessarily have two or more discharge openings for lime, which has the doubtful advantage of permitting a different rate of drawing on the two sides, but except on kilns of large capacity one drawpoint is generally preferred and this may be attained by supporting the central gas flue in an arch, as in *Fig.* 29. The arched central flue may be constructed of cast-iron or steel with water cooling, as described later, in which case it occupies much less space than if made of refractory material.

The chief disadvantages of the central gas flue are the difficulty of control of the gas, its inaccessibility for cleaning, etc., and its tendency to prevent the free down-flow of the lime. In its simplest form the central flue kiln is as shown in *Fig.* 28a where all the gas for the kiln is delivered to the flue and divides itself, without external control, between two or four ports of equal size. These openings should, of course, be designed to be self-clearing, but if partial blockage should occur their inaccessibility makes clearance difficult, and it is not easy to correct the uneven heating of the kiln which may result. To compensate for uneven distribution at the central burner a kiln may be fitted with side burners, used regularly or as auxiliaries to supply supplementary gas to the side that has become cool due to shortage of supply from the central ports. Alternatively, the central flue may be divided into two or four passages with a control valve on each, but this obviously must occupy more space and is more suited to the larger kilns in which it is, in fact, now used.

The tendency for the central flue to hold up the lime above it and to cause sticking and arching in the kiln depends on the proportion of the total cross sectional area that it occupies, and if this proportion is too great excessive sticking is inevitable. However, the application of the gas near the centre and the removal of excessive heat from the walls result in lighter burning and less tendency to stick to the walls which ordinarily compensate for the obstruction of the centre wall.

The actual size of flue and of ports to carry the gas required for lime-burning is not large. It depends on the calorific value of the gas and the pressure drop that may be tolerated. When crude gas is being used it is necessary to allow a margin for partial blockage due to deposition of soot. In all respects hot producer gas is least suitable for small flues; it is sooty, of low calorific value

per cubic foot (*e.g.*, it is about 50 to 60 B.Th.U. per cubic foot if it is at 500 deg. C.) and in ordinary producer practice it is seldom possible to operate at pressures much above atmospheric; the permissible pressure drop is generally only a fraction of an inch water-gauge. Natural gas, on the other hand, is supplied cold, has a calorific value about eighteen times as great (so that one-eighteenth the volume is required), and it is generally available at pressures which permit considerable pressure drop in the flues.

INTRUDED GAS PORTS.—In an attempt to combine the advantages of the central gas port with the ease of control and accessibility of side ports, the intruded gas port was evolved. At first it took the form of a port built of refractory blocks projecting a foot or more into the kiln from the side walls, but these ports soon became worn off nearly flush with the walls unless they were built very strongly, in which case they occupied so much space as to restrict the kiln, and the effect was much the same as if the kiln had simply been reduced in diameter at the gas-inlet zone. Possibly with improved refractories a successful port of this type may be evolved.

At present the only successful intruded gas port is that made of water-cooled metal, which is employed in the kilns shown in *Figs.* 32 and 33. Exact details of the burner are kept secret, but broadly speaking it consists of a heavy tubular casting with open end, in the walls of which are passages for the cooling water. It is supported from the kiln casing and may project any desired distance into the kiln, the diameter of which is therefore practically unlimited. Intruded burners may also be made of heat-resisting steel without water cooling, but the risk of failure under abnormal kiln conditions is a disadvantage.

GAS ENTRY AT DIFFERENT LEVELS.—As already pointed out, the gradual combustion of the gas, so as to have a long zone of nearly uniform temperature, promotes efficiency, and the use of slow-burning gas together with good design of gas and air inlets are of assistance in getting the best results. Another method that has been tried is to admit gas at different levels in the kiln so that the successive combustion of the quantities admitted serves to balance the amount abstracted by calcination without being sufficient to produce too high a temperature. This procedure is often adopted in furnaces, but it is very difficult to apply to a lime kiln and it has not proved a success.

The Height of Kilns.

Consideration has already been given [3] to the space and height required for the calcination of limestone to lime, and the same considerations apply to gas-fired kilns, but two additional factors must be taken into account, namely, the space required for admixture of gas and air and their combustion, and the effect on height of the limited depth of penetration of the gas. It has been shown that small stone requires less space and therefore, for a given diameter, less height for its calcination, but if the burning zone is reduced to a volume less than that required for admixture and combustion this latter volume becomes the con-

[3] "Cement and Lime Manufacture," April, 1937, p. 123, *et. seq.*

trolling factor. Since gas penetration is reduced proportionally to the size of the stone it is evident that gas kilns for small stone must be made high and narrow, in comparison with the dimensions of a mixed-feed kiln for the same size stone. In kilns burning large stone, say 6-in. and upwards, the height of the zone required for calcination generally exceeds that required for combustion, etc., so that the latter may be neglected in considering the height, but with smaller stone, or with stone that packs together to give abnormally low free space, the volume required for combustion becomes of importance. The range of heights of modern gas-fired kilns can be seen by reference to the description of typical kilns given later.

The Shape of the Burning Zone.

In a perfect mixed-feed kiln, in which the stone and fuel are fed in together at the top of the shaft, the shape of the burning zone would be cylindrical, and in actual kilns it approaches more or less closely to that shape. Because of the

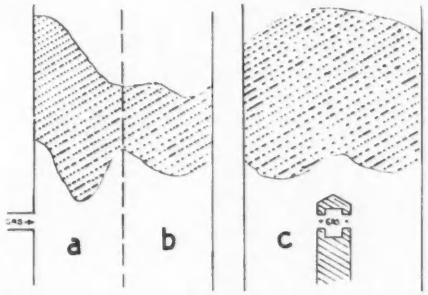


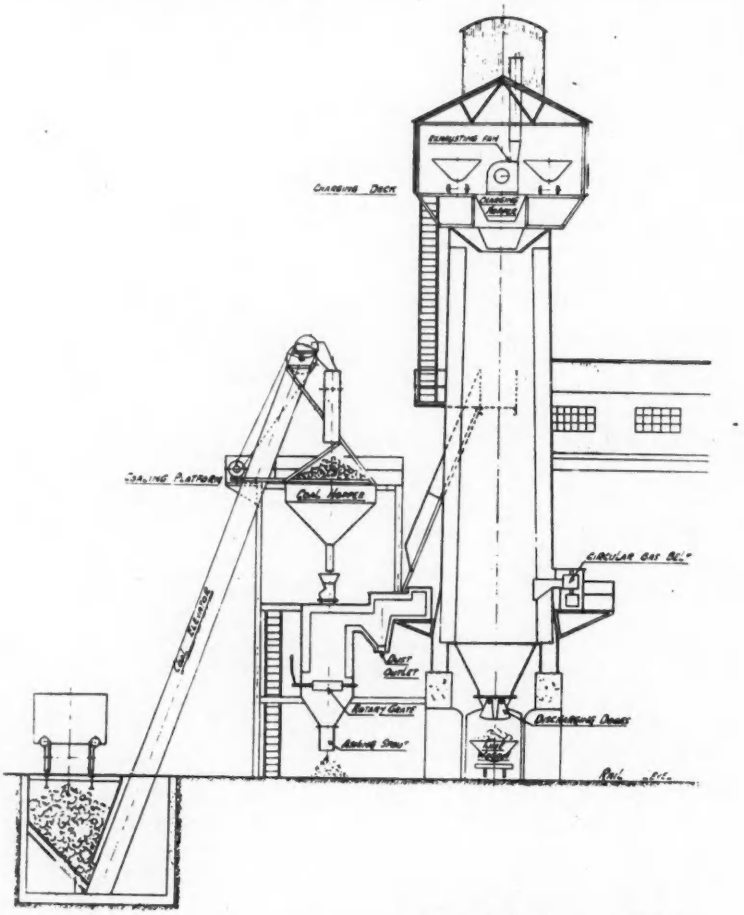
Fig. 30.

impossibility of introducing gas over the whole area of a kiln, the burning zone of a gas kiln can never be a cylinder. Its actual shape under various conditions of introducing the gas would be very difficult to determine. It would require the exploration with a temperature measuring device of the whole cross-sectional area of the shaft at a number of different levels in the burning zone. *Fig.* 30 has been drawn to suggest the probable approximate shapes under different conditions of gas inlet, but it is mainly speculative and it varies with the kiln diameter and the nature of the gas, etc. Furthermore, in the kiln with side gas-inlets the temperature in the different zones varies; for example, immediately over the gas inlet the zone is long and relatively cool whilst between the ports it is short but hot.

Producer Gas for Lime Burning.

A gas producer is essentially a deep fire-box in which no air is admitted above the fuel bed, and there are plants known as semi-gas-producers which represent an intermediate stage between the ordinary fire-box and a full gas producer. Semi-gas-producer-fired kilns, however, will be discussed later when dealing with furnace-fired kilns.

In producer gas a considerable proportion of the total heat (usually about 12 per cent.) is represented by sensible heat and consequently it is desirable to avoid cooling losses between the producer and the kiln. For this reason, and to reduce the cost of flues, the producers should be placed as closely as possible to



(Messrs. Priest Furnaces, Ltd).

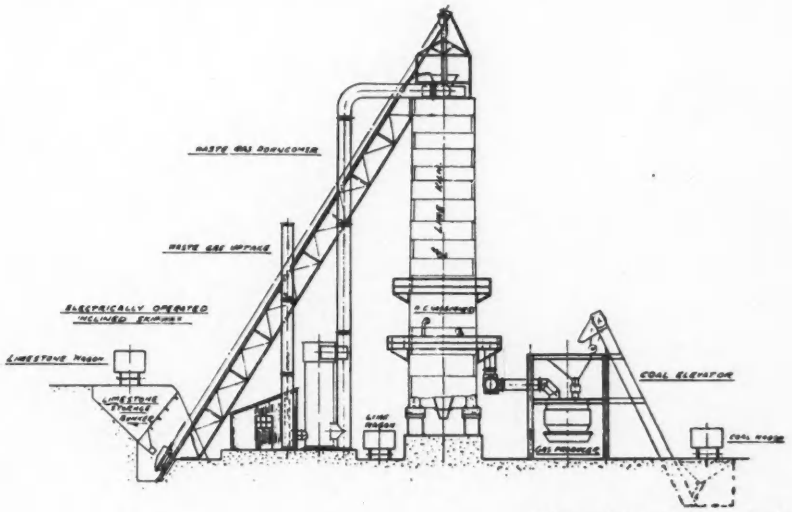
Fig. 31.—Gas-fired Kiln for Chalk.

the kilns. Attached producers, which are built on to the sides of the kiln and are an integral part of the kiln structure, are therefore often used. They are employed in the plant shown in *Fig.* 31. These producers are made in small sizes, so that two, three, or four are required to each kiln. They are of rectangular

section and have at the bottom a form of grate which can be rotated to discharge the ash, as well as serving as an air distributor. They may be fed mechanically or otherwise and are so small in area that sufficiently even fuel distribution is easily attained.

The more usual cylindrical form of producer, manually operated, is also frequently used. Being simple in construction and robust, its maintenance cost is low, but it requires rather more attention than the small type and the labour of poking it is more strenuous.

Large lime burning plants are best operated by high-capacity mechanical producers as shown in *Fig.* 32. Labour is then reduced to a minimum; in fact, the whole plant can then be mechanically operated.



(Messrs. Priest Furnaces, Ltd.)

Fig. 32.—Gas-fired Kiln with Water-cooled Gas Ports.

Producer gas contains tar and soot and the flues between producers and kiln should be designed for easy cleaning and burning out. Poor design entails a waste of time at the periodical burning out that is necessary when gasifying any bituminous fuel.

In exceptional circumstances, for example, when a very pure lime is required, it may be necessary to cool and clean producer gas for lime-burning. The necessary plant is much the same as that used in cleaning gas for use in gas engines. It embodies dust chambers, coolers, scrubbers, etc., and a heat exchange may be effected between clean washed gas and hot dirty gas to increase slightly the overall thermal efficiency of the process.

Steam and Carbon Dioxide in Gas Products.

In gasifying coal or coke it is necessary to use steam or another agent with the air to reduce the temperature of the fuel bed by its endothermic reaction and to convert some of the sensible heat of reaction into chemically latent heat. Steam is nearly always used, but carbon dioxide is a possible alternative agent and the availability of a gas rich in carbon dioxide at the lime kiln exhaust suggests its use. It has been fairly widely used for the same purpose in furnace-fired kilns (the Eldred process—to be discussed later) but its use instead of steam in full gas producers is rare.

Steam for use in lime-kiln gas producers is ordinarily raised in a small boiler operating at low pressure. Sometimes the steam is used to inject air into the producers, but this procedure limits the control on the steam-air mixture and it should be used only when electrical power for operating a blowing fan is not available. Preferably the air is supplied by a fan and saturated steam is mixed with it before it enters the producer, when the temperature of the mixture is a measure of the air : steam ratio. The exhaust gases from a lime kiln burning limestone (not wet chalk) nearly always contain amply sufficient heat to generate, in a waste heat boiler, the steam required by the producers. The temperature margin, however, is not wide, and it is necessary to avoid much reduction of temperature between the kiln and the boiler and also to operate the boiler at low pressure so that the temperature difference between gases and water is as high as possible. Loss of heat can be avoided by heat insulation of the exhaust gas ducts but a more serious source of temperature reduction is usually the air leakage into the exhaust gases before they enter the boiler. Such leakage often occurs at the kiln charging door, and special care should be taken to reduce it to a minimum and avoid leakage elsewhere.

The employment of kiln gases, instead of steam, to reduce the temperature of the fire-bed and prevent clinkering, and to increase the latent heating value of the gas made, has several drawbacks and limitations. The exhaust gases from a gas kiln seldom contain much more than 30 per cent. carbon dioxide, so that about 7 parts of inert gas are introduced for every 3 parts of carbon dioxide and the gas made is correspondingly diluted and thereby made less efficient as a heating agent and more difficult to burn completely. Also the diluted air used in the producer tends to leave a higher carbon content in the ashes. Another factor is the different reactivity of steam and carbon dioxide on hot carbon. The former is the more reactive and therefore, even at the same dilution, the more effective for the purpose of reducing temperature. However, for equal volumes the endothermic effect of steam ($H_2O + C = H_2 + CO - 29{,}000$ cals.) is less than that of carbon dioxide ($CO_2 + C = 2CO - 39{,}000$ cals.), and kiln exhaust gas is being used for the purpose at a few plants. No doubt the more reactive fuels are better adapted to its use, and it is also more suited to kilns in which a magnesian or hydraulic lime is being burnt, requiring less heat than a pure lime and necessitating a low kiln temperature. The use of exhaust gas, in fact, reduces the calorific value of the producer gas made, which therefore burns with a cooler flame in the kiln.

Natural Gas and Other Rich Gases.

The use of natural gas, town gas, and coke-oven gas may conveniently be considered together. Natural gas is now employed on many lime plants in areas where it is available at low cost, and coke-oven gas is used to a limited extent. From the point of view of application these gases are nearly ideal. Their high heating values, cleanliness, and temperature, and the fact that they are generally available at pressure, make it easy to control and measure their flow and reduce to a minimum the size of flue required. The ports admitting the gas to the kiln can be made very small and a high velocity of gas achieved at the point of entry, which, in some measure, assists penetration.

The high calorific value of these gases tends to produce high local temperatures in the kiln which may cause over-burning of the lime and destruction of the lining, and consequently the gas is sometimes diluted or " tempered " by admixture of an inert gas. The kiln exhaust gas is suited to this use, and a simple arrangement of flues will serve to admit a sufficient quantity of it to the gas flue to give the required result. In modern kilns, however, excessive temperature is generally avoided by efficient design of the gas-inlet arrangements, thereby avoiding the extra cost and decreased efficiency of dilution.

Blastfurnace Gas.

Blastfurnace gas is often available at very low cost or as a waste product, and therefore it may be a most economical fuel for lime burning. Since lime is used in large quantities in steel furnaces, kilns burning it with the aid of blast-furnace gas are of considerable economic importance.

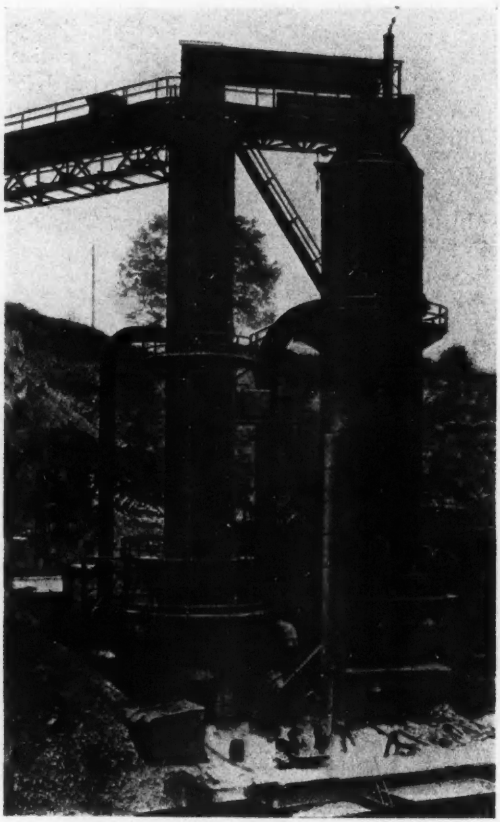
Blastfurnace gas varies in heating value from about 85 to 115 B.Th.Us. and from modern furnaces it consists of carbon monoxide, carbon dioxide, and nitrogen, with only small amounts of other gases. Efficient blastfurnaces also tend to give a gas of low heating value. Calculation shows that lime-burning with a low-value gas is impracticable, because the amount of heat above lime-burning temperature available from its combustion is too small. It is therefore generally enriched by the addition of coke-oven gas to raise the calorific value to about that of producer gas. A high-value blastfurnace gas may be used without enrichment, especially if preheated, but ordinarily it is preferred to enrich it when coke-oven gas is available. Control of the mixture may be automatically maintained, if desired, to a fixed calorific value by valves controlled by a continuously operating gas calorimeter.

The exhaust from a kiln operating on blastfurnace gas, or mixtures of it, is seldom passed through a waste-heat boiler, because steam is not required on the lime plant. Nevertheless, it is desirable to reduce its temperature before it enters the exhauster to save power and to avoid rapid destruction of the exhauster. Heat may be recovered, and the efficiency of the plant raised, by a heat exchange between the exhaust gas and the combustible gases, and this is of special value and importance when burning an unenriched blastfurnace gas, because the temperature of the exhaust gases is then high, the weight of those gases is large, and the improvement in efficiency that may be effected is considerable. The clean

cold gas is passed through a tubular heater and the hot kiln gases countercurrent outside the tubes.

Typical Gas-Fired Kilns.

Modern gas-fired kilns in use in Great Britain vary in capacity from about 18 tons up to 80 tons a day. Cylindrical kilns with gas ports flush with the walls have capacities up to 40 tons a day but normally they are unsuitable above about

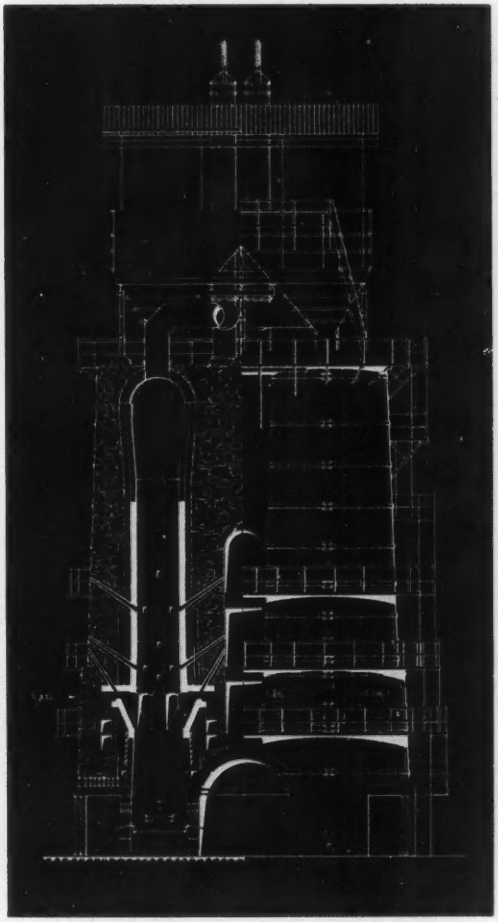


(Messrs. Priest Furnaces, Ltd.)

Fig. 33.—Gas-fired Kilns.

30 tons. A typical kiln of this kind, burning limestone, is the smaller kiln shown in *Fig.* 33 (other kilns built by the same kiln constructors were illustrated in "Cement and Lime Manufacture," March, 1937, pp. 75 and 76, *Figs.* 8 and 9). These kilns vary in overall height from 80 ft. to 100 ft., the normal height being

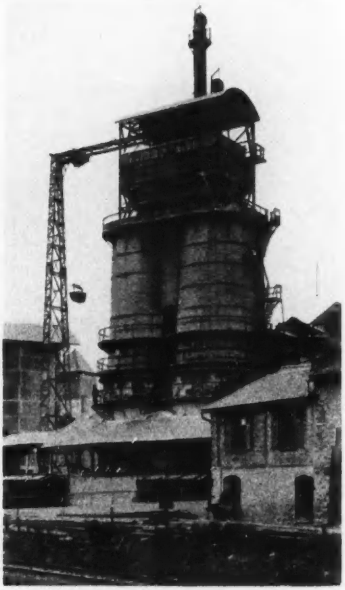
about 85 ft. The internal diameter varies from 6 ft. 6 in. to 9 ft., but they may open out wider in the storage zone at the top, as in *Fig.* 9. The exhaust gases are drawn off at a point below the top of the kiln, leaving the upper section as a



(Dr. C. Otto, Bochum.)

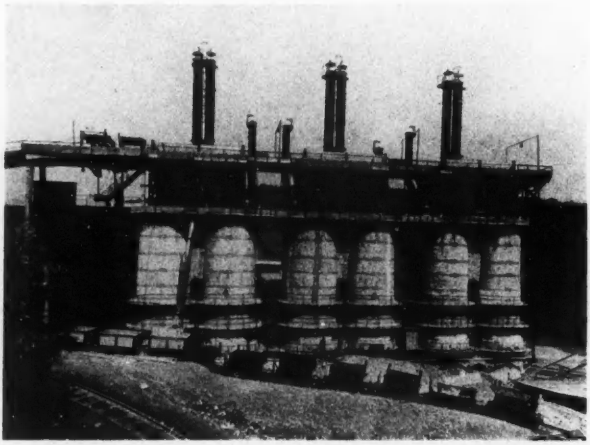
Fig. 34.—Gas-fired Kiln.

storage zone which holds sufficient stone to carry over a night or even a week-end without the level falling below the draw-off point. In this way resistance through the kiln is kept constant and the temperature of the exhaust gases fluctuates only slightly.



(Dr C. Otto, Bochum.)

Fig. 35.—Pair of Gas-fired Kilns.



(Dr. C. Otto, Bochum.)

Fig. 36.—Battery of Gas-fired Kilns.

Kilns of the same type for use with chalk and similar soft porous stone or stones are shorter and the gases may be drawn off from the top, as in *Fig.* 31. They must then be charged night and day, but have the advantage of a maximum effective height for heating with the minimum crushing load and distance of travel of the lime.

Continental kilns of oval cross section are shown in *Figs.* 34, 35 and 36. They are built with limestone casings made of rough stone set in cement mortar, reinforced with steel bands to reduce cracking. The capacities of these kilns vary from 20 to 85 tons a day with induced draught, but more often they operate under natural draught at about two-thirds of that capacity. The width varies only

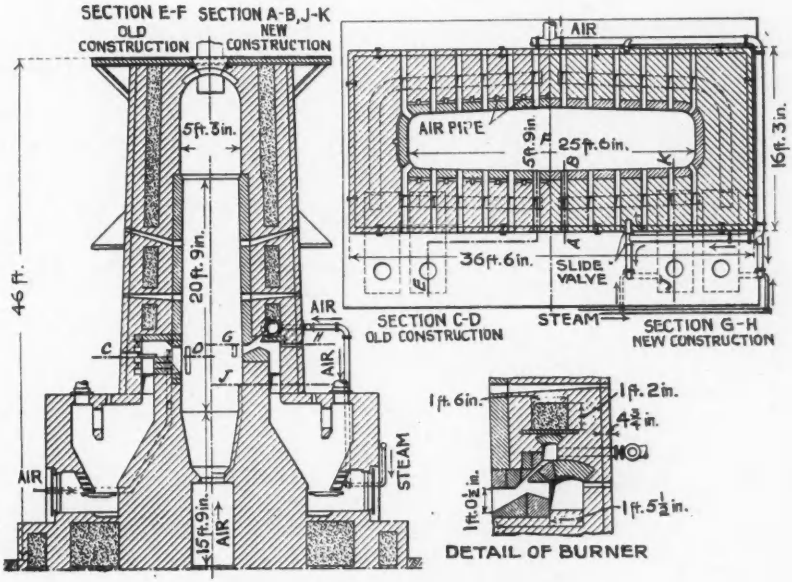


Fig. 37.—Gas-fired Kiln in Poland.

slightly in kilns of different capacity, the limits being 6 ft. and 7 ft. as the length of the short axis of the oval. The long axis varies between 10 ft. and 23 ft. and the height from 60 ft. to 70 ft. The largest kilns, of 85 tons per day capacity, have ten gas inlets, five on each side, and the smallest kilns built have only two gas inlets. Producer gas, blastfurnace gas, and coke-oven gas are burnt in these kilns.

A kiln even more elongated in cross-section is shown in *Fig.* 37. It is 5 ft. 9 in. by 25 ft. 6 in. at the gas-inlet zone and has 24 gas ports, 12 on each side. This large kiln has a production of only about 50 tons per day but the fuel efficiency is said to be high. The drawing shows the original design of the kiln, which

proved to be inefficient, and the modifications adopted to improve efficiency, the most important of which is the addition of steam to the air used in the producer.

Kilns with central gas ports are used mainly in England and the United States. At present they have capacities from 30 to 100 tons a day, but they can be built to produce almost any desired output. The diameter varies from 8 ft. to 16 ft. in cylindrical kilns, but in the United States these kilns are also built with a shaft of oval cross-section. For example, the shaft may be an oval or rounded rectangle with axes of 9 ft. and 7 ft., and an area of about 60 sq. ft., and a kiln of this size is said to have a capacity of 50 to 60 short tons (about 45 to 54 long tons) a day, or nearly a ton per day per square foot of shaft area[4]. The overall height of kilns with central gas ports is much the same as that of those with outside ports, but the work done in that height is greater because they can be and are operated at higher output.

Water-cooled intruded-burner kilns are shown in *Figs.* 32 and 33 (the larger kiln) which produce up to 80 tons a day. The height of existing kilns of this type varies from 80 ft. to 100 ft. and the diameter up to 14 ft., but it could be much more if a higher output were desired. Water-cooled intruded gas ports are also fitted to smaller kilns with a capacity of 30 tons a day and upwards. Kilns of this type are in operation burning producer gas and blastfurnace gas enriched with coke-oven gas.

Future Developments of Gas-Fired Kilns.

The main tendency in gas-fired kiln construction to-day is towards larger units and higher outputs for a given size of kiln, but when a high suction at the exhauster is required to produce the high output the plant is seldom economically sound. The proper application of the gas, however, has increased the thermal efficiency of gas kilns, and this increase is accompanied by a decrease in the amount of gases to be exhausted per ton of lime and by a lower temperature, so that exactly the same conditions of suction produce much more lime. In future it seems likely that this improved gas application will entirely supersede older methods and that kilns with only side ports will cease to be built.

It has already been shown[5] that the conditions which ensure efficiency and high quality of product are opposed to each other and in the same way a high output per unit of area is opposed to quality. Efficiency of design and control of operation can effect a satisfactory compromise and at low fuel consumption and high capacity produce from a pure limestone a lime of high quality judged by present standards. Nevertheless, it remains a fact that the best and most uniform lime is made in a kiln operated slowly and at low temperature, which entails greater fuel consumption, and some impure limes demand this treatment for their production in saleable quality. If the heat in the exhaust gases could be made use of, for example for stone drying, the combination of such a kiln with the subsidiary process would be highly efficient, and in the future it is probable that combinations of this kind will be employed.

(To be continued.)

[4] "Rock Products," September, 1937, p. 66.
[5] "Cement and Lime Manufacture," January, 1937, p. 7.

Recent Patents Relating to Cement and Lime.

Slag Cements.

464,720.—Blondiau, L., and Soc. Anon. des Ciments de Thieu. April 23, 1936.

In slag cements made by grinding together blastfurnace slag and a substantial proportion of calcium sulphate the sulphate is calcined at a temperature between 850 deg. C. and the temperature of decomposition, for a short time (5 to 10 minutes) the particle size being such as to ensure uniform calcination, e.g., less than 9 mm. diameter. The temperature is dependent on the amount of impurity present, and should be as high as possible. Suitable proportions are 830 kg. of slag to 170 kg. of calcium sulphate. Portland cement clinker or lime may also be added to the cement.

Cement and Lime.

461,323.—Jorgensen, M. Vogel-. Aug. 12, 1935.

In the manufacture of cement by the wet process or the production of lime by burning lime slurry the raw slurry is converted wholly or partly into froth or foam and is subjected to treatment in this form. The conversion into froth, which may take place at various stages in the course of manufacture, is stated to facilitate the grinding and mixing of the raw materials, the conveying of the slurry through pipes, and the drying operation. The slurry may be converted into froth by beating or forcing air through it or by adding gas generating substances, e.g., aluminium powder or calcium carbide; the calcium carbide may be impregnated with resin, oils, tars, silicates of low melting point, etc., in order to reduce the rate of evolution of gas. Substances which lower the surface tension of the slurry, such as soaps, e.g., resin soaps, gelatin or glue or mixtures thereof, should be added to the slurry or an ingredient thereof before it is beaten or aerated; 0.05 to 2 per cent. of the substance may be added. The slurry may be treated to lower its viscosity before it is converted into froth, e.g., the viscosity of cement slurry may be lowered by adding sodium hydroxide to cement slurry. The drying of the slurry may be effected in apparatus of the type in which the slurry is spread on moving chains that pass through a space traversed by hot gases.

Waterproofing Cement, etc.

460,736.—Howe, W. J. Dec. 11, 1935.

A process for waterproofing cement, concrete, lime-plaster, and the like lime-containing compositions comprises incorporating therein, during the admixture of the ingredients of these compositions with water or subsequently thereto, an aqueous dispersion of a higher fatty acid together with a dispersing agent comprising sulphonated castor oil or sodium silicate and a stabilising agent comprising glue or size. About 4½ oz. of fatty acid in the form of the dispersion may be incorporated in 1 cwt. of cement. Fatty acids specified are stearic, palmitic, oleic, linoleic, linolenic, and ricinoleic acids. In an example, 1 part by weight of glue or size is dissolved in 480 parts of boiling water; 30 parts of sulphonated castor oil followed by 54 parts of stearic acid are added whilst the mixture is still hot, and the mixture passed through an emulsifying machine or agitated until cool.

SUPER REFRACTORIES for CEMENT KILNS

ALITE No. 1. 68% ALUMINA
Refractory Standard 3250° Fahr.
ALITE B. 57% ALUMINA
Refractory Standard 3180° Fahr.
ALITE D. 41% ALUMINA
Refractory Standard 3150° Fahr.

E. J. & J. PEARSON, LTD.,
STOURBRIDGE, ENG.

BOOKS ON CONCRETE

CODE OF PRACTICE.

"EXPLANATORY HANDBOOK ON THE NEW CODE OF PRACTICE FOR REINFORCED CONCRETE," by W. L. SCOTT, M.Inst.C.E. and W. H. GLANVILLE, D.Sc., A.M.Inst.C.E. With a foreword by Sir George Humphreys, K.B.E., M.Inst.C.E. (Chairman of the Committee responsible for the new Code).—The new Code, issued in 1934, and the Report of the Committee are printed in full. Every Clause requiring explanation is thoroughly discussed by authors actively engaged in the preparation of the Code. Tables are given for the rapid design of columns, and to give the moments in slabs. The coefficients of the bending moments have been determined for ratio of dead load to live load. xii + 143 pages, 23 illustrations, 37 tables. Price 8s. (by post 8s. 6d.).

DESIGNERS' HANDBOOK.

"REINFORCED CONCRETE DESIGNERS' HANDBOOK," by CHAS. E. REYNOLDS, B.Sc., A.M.Inst.C.E.—An up-to-date English book presenting in *one volume* complete data for the design of all classes of reinforced concrete structures. Tables cover the design of every description of reinforced concrete structure and worked Examples show how the Tables are used. The short cuts and simplified methods essential for rapid solutions of designing problems are clearly set out. xiv + 282 pp., 40 design tables, 51 illustrations. Price 15s. (by post 15s. 9d.).

FORMWORK.

"DESIGN AND CONSTRUCTION OF FORMWORK FOR CONCRETE STRUCTURES," by A. E. WYNN, B.Sc., A.M.Am.Soc.C.E.—Gives complete designs for formwork for every type of plain and reinforced concrete structure, from simple footings to arch bridges, with tables from which the size and quantity of timber required for any type or size can be seen at a glance. xii+200 pp., 219 illustrations, 12 folders, 11 design tables. Price 20s. net (by post 20s. 9d.).

ESTIMATING.

"ESTIMATING AND COST KEEPING FOR CONCRETE STRUCTURES," by A. E. WYNN, B.Sc., A.M.Am.Soc.C.E.—Describes in fullest detail methods of estimating, cost-keeping, and book-keeping particularly suitable for concrete constructors. Ensures the achievement with a minimum of effort of the accuracy in estimating essential for successful contracting. Reproductions are given of all the forms required. 239 pages, 92 illustrations, 2 folders. Price 15s. (by post 15s. 6d.).

RESERVOIRS AND TANKS.

"REINFORCED CONCRETE RESERVOIRS AND TANKS," by W. S. GRAY, B.A., M.A.I., A.M.Inst.C.E.I.—Deals in a thoroughly practical manner with the design and construction of plain and reinforced concrete reservoirs and tanks, swimming baths and pools, and other water-containing structures both above and below ground level. Valuable information is included on the design and construction of tanks in ground subject to subsidence by mining and on the stability of tanks in waterlogged ground. Complete designs for reservoirs, tanks, swimming baths, etc., with details of expansion joints, floor and wall joints, reinforcement for walls and floors, formwork, etc. 174 pages, 119 illustrations. Price 10s. (by post 10s. 6d.).

WATER TOWERS, BUNKERS, SILOS AND GANTRIES.

"REINFORCED CONCRETE WATER TOWERS, BUNKERS, SILOS AND GANTRIES," by W. S. GRAY, B.A., M.A.I., A.M.Inst.C.E.I.—Deals with every problem in the design and construction of reinforced concrete water towers, bunkers, silos and gantries. Gives labour-saving diagrams. The treatment of the columns of structure subject to wind pressure is thoroughly discussed with worked examples. Other problems thoroughly dealt with are the transmission of heat through concrete walls, the design of tanks to hold hot liquids, and the insulating properties of various materials. Working drawings are included of completed structures. 228 pages, 170 illus., 2 folders. Price 10s. (by post 10s. 6d.).

SURFACE FINISHES.

"CONCRETE SURFACE FINISHES, RENDERING, AND TERRAZZO."—Detailed descriptions of every practical method of finishing concrete and improving the appearance of old and new structures. All the methods described have been successfully carried out. Drawings, photographs, and detailed information on the methods of specialist contractors. 136 pp., 84 illus., 6 colour plates. Price 6s. 6d. (by post 7s. anywhere in the world).

CONCRETE ROADS.

"DESIGN AND CONSTRUCTION OF CONCRETE ROADS," by R. A. B. SMITH, M.C., A.M.Inst.C.E., A.C.G.I.—Prepared with the collaboration of many County and Borough Surveyors. No further information is needed to enable the reader to design and construct a sound road of any width on any subsoil to carry any volume of traffic. Deals entirely with English practice. A complete Specification is a valuable feature. The selection of materials, grading, proportioning, mixing and curing are dealt with from the point of view of practical work; economical and practical methods are described and illustrated. Construction of Cement-Bound roads and Compressed Concrete roads is fully described and illustrated. Chapter on Repair and Maintenance Work. 260 pages, 128 illustrations, xii tables. Price 8s. 6d. (by post 9s. anywhere in the world).

STUDENTS' TEXTBOOK.

"THE ELEMENTS OF REINFORCED CONCRETE DESIGN," by HADDON C. ADAMS, M.A. (Cantab.), A.M.Inst.C.E.—A complete course for the student. Explains the principles of reinforced concrete design with the most elementary mathematics. Gives fully worked examples of designs for slabs and beams, columns, and footings. Diagrams and tables facilitate rapid design, so that the volume is a Handbook as well as a Textbook. 142 pp., 101 illustrations, 11 design charts, 9 tables. Price 6s. net (by post 6s. 6d.).

SIMPLE STRUCTURES.

"CONCRETE CONSTRUCTION MADE EASY," by L. TURNER, B.Sc., A.M.Inst.C.E., and ALBERT LAKEMAN, L.R.I.B.A., M.I.Struct.E.—Gives full designs with tables and all information necessary to enable builders to erect foundations, walls, columns, floors, roofs, staircases, beams, water tanks, retaining walls, stanchion bases, lintels, formwork, etc. 113 pp., 65 illus., 16 tables. Price 3s. 6d. net (by post 4s.).

ELEMENTARY GUIDE.

"ELEMENTARY GUIDE TO REINFORCED CONCRETE," by ALBERT LAKEMAN, L.R.I.B.A., M.I.Struct.E.—Specially written for the beginner, on the assumption that he has no knowledge of the subject whatever. The author makes clear the principles governing the design of reinforced concrete in a way that can be readily grasped. 94 pages, 79 illus. Price 2s. (by post 2s. 3d.).

HOUSES, BUNGALOWS.

"CONCRETE COTTAGES, BUNGALOWS, AND GARAGES," by ALBERT LAKEMAN, L.R.I.B.A., M.I.Struct.E.—Contains all the information necessary to build small houses in concrete, with copious illustrations. Designs for cottages, bungalows, and garages have been specially prepared, and with each design is given all the information necessary for its erection, plans, sections, full working drawings, and quantities. Chapters are included on alternative methods of construction. 120 pp., 86 illus. Price 5s. net (by post 6d. extra).

PRE-CAST CONCRETE.

"MANUFACTURE AND USES OF CONCRETE PRODUCTS AND CAST STONE," by H. L. CHILDE.—Gives all the available information on pre-cast concrete, from tiles to architectural cast stone. Selection of materials, grading and proportioning, mixing, curing, surface treatment, etc., are fully covered. Moulds for various products are illustrated by more than 100 working drawings and illustrations of moulds in wood, plaster, sand, gelatine, concrete, etc. 304 pp., 265 illus. Price 6s. (by post 6s. 6d.).

"PRE-CAST CONCRETE FACTORY OPERATION," by H. L. CHILDE.—Gives detailed descriptions of works producing cast stone, decorative units, paving flags, roofing and floor tiles, kerb and channel, breeze and concrete slabs, posts, coloured concrete, etc. 180 pages, 146 illus. Price 2s. 6d. (by post 4s.).

"MOULDS FOR CAST STONE AND PRE-CAST CONCRETE," by F. BURREN and G. R. GREGORY.—Contains large-scale clear working drawings, with explanatory notes, for making wood and plaster moulds for various pre-cast concrete units. 96 pp. Price 4s. (by post 4s. 6d.).

Detailed Prospectuses sent on request

CONCRETE PUBLICATIONS LIMITED, 14 DARTMOUTH STREET, WESTMINSTER, S.W.1